



## Ensuring Economically Feasible Biogas Projects by Optimisation of the Value Chain

Jensen, Ida Græsted; Juul, Nina

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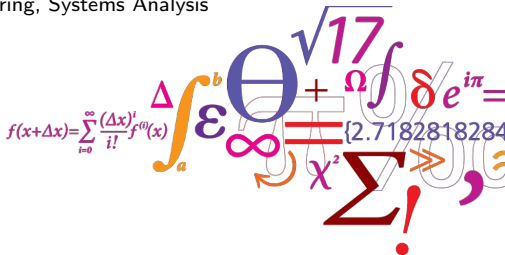
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# Ensuring Economically Feasible Biogas Projects by Optimisation of the Value Chain

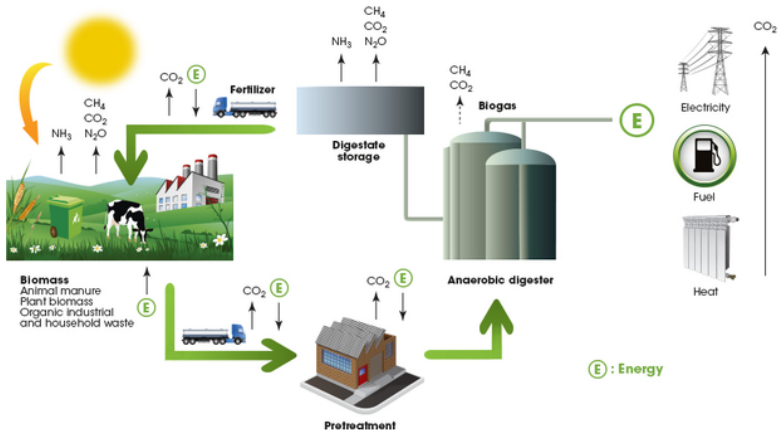
Ida Græsted Jensen MSc & Nina Juul MSc PhD

Department of Management Engineering, Systems Analysis

e-mail: idje@dtu.dk

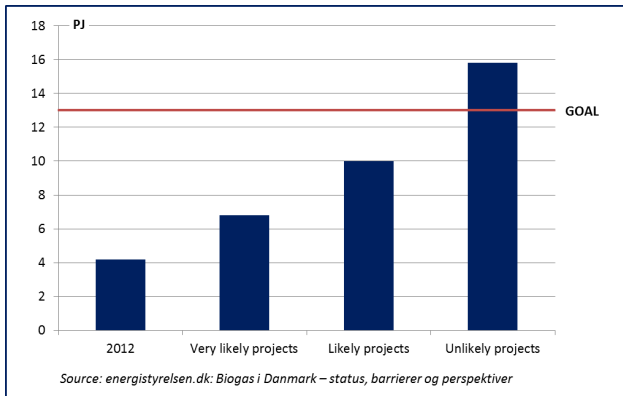


# The system



## Motivation for using biogas

- ▶ High share of wind energy  $\Rightarrow$  need of an alternative electricity source
- ▶ In 2020, 50% of all manure must be used for biogas production - corresponding to approximately 13 PJ



# What is biogas?

Biogas is gas based on waste or other methane sources, e.g.:

- ▶ Animal manure
- ▶ Deep litter
- ▶ Household waste
- ▶ Waste water
- ▶ Energy crops

Biogas can be produced by:

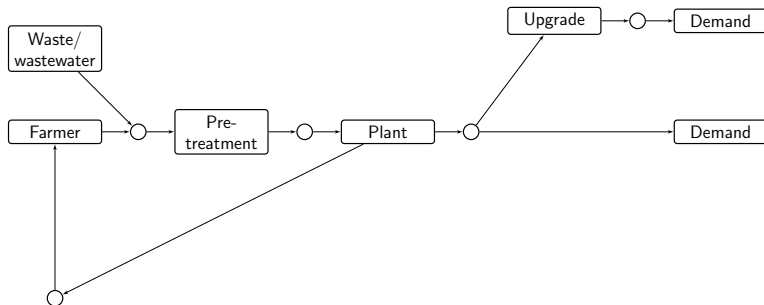
- ▶ Thermal gasification
- ▶ **Anaerobic digestion**



# The plant level model

Objective:

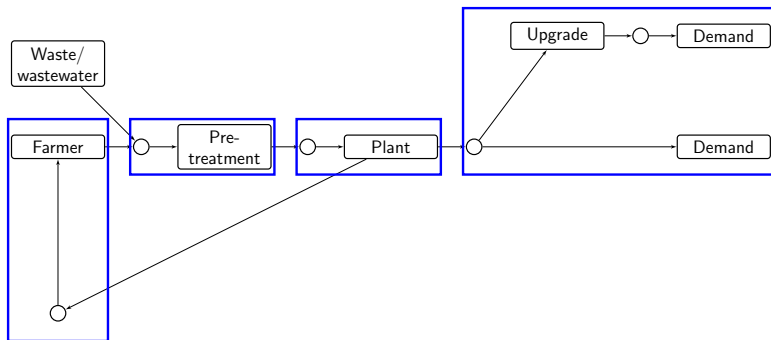
- ▶ Optimise the production of biogas while ensuring economic feasibility for all partners



# The plant level model

Objective:

- Optimise the production of biogas while ensuring economic feasibility for all partners

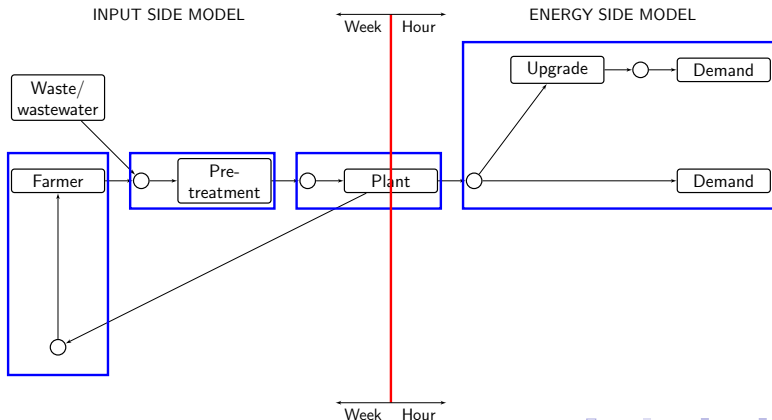




# The plant level model

Objective:

- Optimise the production of biogas while ensuring economic feasibility for all partners



## Input side model

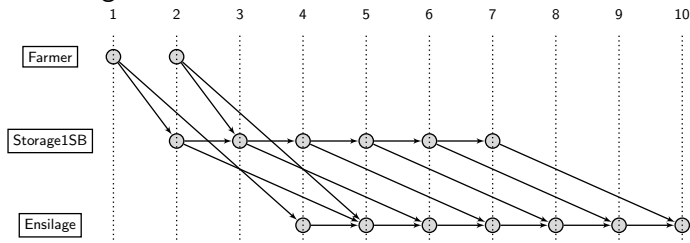
More complicated than the output side:

- ▶ Flow of different biomasses
- ▶ Both mass and energy potential must be accounted for:
  - ▶ Mass needed for capacities and fertiliser output
  - ▶ Energy potential needed for the final biogas yield - changes during storage and pretreatment

# Flow model

- ▶ A 3D graph network: Dimensions are process  $p$ , time  $t$  and biomass potential  $e$
- ▶ A variation of a minimum cost multi-commodity flow problem with node capacities

Small segment of the model - shown in 2D:



# Variables

- ▶  $x_a$ : Flow on arc  $a$  (arc defined by:  $(i, p, t, e, p', t', e')$ )
- ▶  $c_p$ : Capacity of process  $p$
- ▶  $u_{o,p}$ : If  $p$  is owned by owner  $o$
- ▶  $u_{o,p,o',p'}^{trans}$ : If  $p$  is owned by owner  $o$  and  $p'$  is owned by owner  $o'$
- ▶  $x_{o,p,o',p'}^{trans}$ : How much is transported from process  $p$  owned by owner  $o$  to  $p'$  owned by owner  $o'$

# Objective and simple constraints

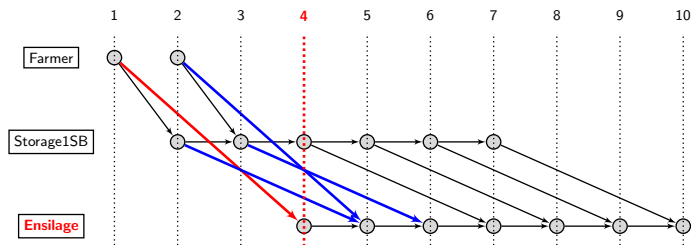
Objective:

$$\begin{aligned} \max Z = & \sum_{a \in \mathcal{A}^{plant}} (p^{gas} BMP_{ie} + p^{fert}) x_a \\ & - \sum_{a \in \mathcal{A}} OPEX_{p,p'} x_a - \sum_{p \in \mathcal{P}} CAPEX_p c_p \\ & - \sum_{(p,p') \in \mathcal{P}} \sum_{(o,o') \in \mathcal{O}} TRANS_{o,p,o',p'} x_{o,p,o',p'}^{trans} \end{aligned}$$

Simple(st) constraints:

- ▶ Flow: includes mass loss for each process
- ▶ Input: what biomasses are available in each time step
- ▶ Maximum biomass type: restrictions on e.g. percentage energy crop of total mix

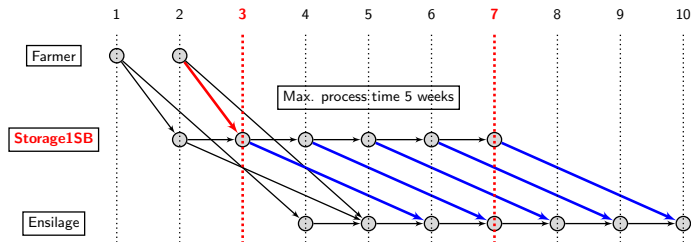
# Capacity constraint



$$\sum_{\text{all red edges}(p,t)} x_a + \sum_{\text{all blue edges}(p,t)} x_a \leq c_p$$

$$\forall p \in \mathcal{P}, t \in \mathcal{T} | (p, t) \in A^{in}$$

# Process time



$$\sum_{\text{All red edges}(i,p,t,e)} x_a \eta_{i,p,t} \leq \sum_{\text{All blue edges}(i,p,t,e)} \frac{x_a}{(\eta_{i,p,p})^{(t'-t)}}$$

$$\forall i \in \mathcal{I}, p \in \mathcal{P}, t \in \mathcal{T}, e \in \mathcal{E} | (p, t, e) \in A^{\text{diff}}$$

# Ownership constraints

- ▶ One owner per process:

$$\sum_{o \in \mathcal{O} \mid (p,o) \in \mathcal{PO}} u_{o,p} = 1 \quad \forall p \in \mathcal{P}$$

- ▶ Same owner for consecutive processes:

$$u_{o,p} + 1 \geq u_{o,p'} + u_{o,p''} \\ \forall o \in \mathcal{O}, i \in \mathcal{I}, (p, p', p'') \in \mathcal{P}^i \wedge p' < p < p''$$



# Transportation constraints

- ▶ If two processes are owned by different owners:

$$u_{o,p,o',p'}^{trans} + 1 \geq u_{o,p} + u_{o',p'}$$
$$\forall \{(p, p') \in \mathcal{P}^{comb}, (o, o') \in \mathcal{O} | (p, o), (p', o') \in \mathcal{PO}\}$$

- ▶ Amount transported between different owners:

$$x_{o,p,o',p'}^{trans} \geq \sum_{a \in \mathcal{A}(p,p')} x_a - M(1 - u_{o,p,o',p'}^{trans})$$
$$\forall \{(p, p') \in \mathcal{P}^{comb}, (o, o') \in \mathcal{O} | (p, o), (p', o') \in \mathcal{PO}\}$$

# Results

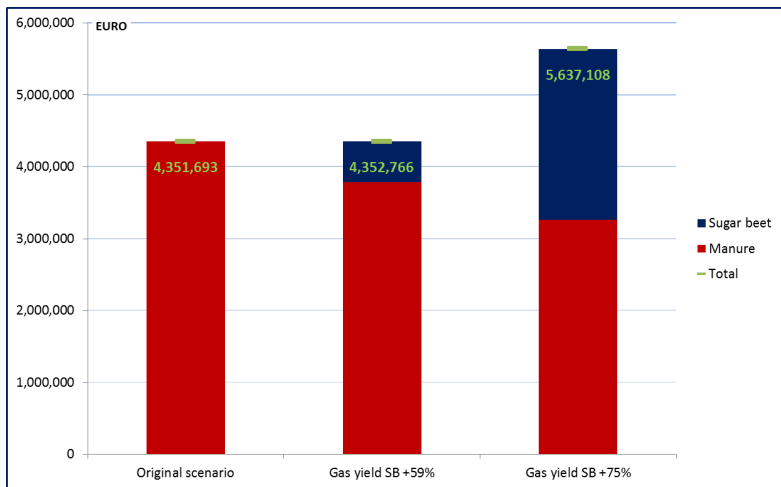
Case considers co-digestion of sugar beet (SB) and pig slurry (PS).

- ▶ All cost functions are linear
- ▶ Data is preliminary - the costs of each process is partly being determined in the BioChain project



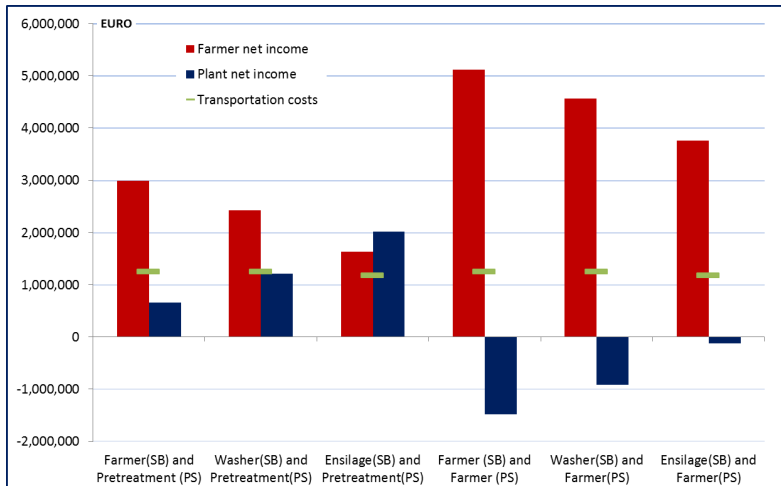


# SB gas yield increased



- Uncertainty on the gas yield of SB can make co-digestion profitable

# Income for farmer and plant - different ownerships



- Ownership of each process is highly relevant for partners in the project

## Next step

- ▶ Data on the input side must be validated
- ▶ Constraints for feasibility of ownership included
- ▶ Detailed restrictions on the plant, e.g. seasonal variation
- ▶ Transportation more detailed included
- ▶ CAPEX and OPEX included as piece-wise linear functions

# Is it really worth the effort?

Today in Denmark:

- ▶ Existing biogas plants typically have long time contracts on price of output, i.e. the variation on prices might not be used in practice
- ▶ Existing biogas plants cannot control what the biogas is used for due to the ownership structure



## Is it really worth the effort?

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This will hopefully change over the next years!